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IMPROVEMENT OF WELDMENT BY POST WELD HEAT TREATMENT OF LOW CARBON STEEL

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ABSTRACT

Low carbon steel is also known as Corten steel. It has a lower level of carbon (0.05% to 0.3%). Low carbon steel is widely used in the constructional industry for building bridges, buildings, and telecommunication towers etc. The major problems faced during welding of this material are to form residual thermal stresses, cracking, lack of fusion etc. The Laser beam welding (LBW) process is carried out to make a permanent joint. The Laser welded A588 plates are kept in the furnace, heated up to 850°C and maintained for two hours and then cooled to room temperature by furnace cooling, water quenching and air cooling. In this research work, an attempt is made to investigate the Vickers hardness and metallurgical properties of PWHT of Laser welded Corten A588 Grade steel plate.

KEYWORDS: Post Weld Heat Treatment (PWHT), Heat Affected Zone (HAZ), LBW, Low Carbon Steel & Corten A588 Grade Steel

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Original Article

INTRODUCTION

Weathering (Low carbon) steel market is estimated to be 1 Billion USD in 2019 and is projected to reach 1.6 billion by 2024. The major application of corten steel is building and bridge construction. During the last decades the usage of corten steel has increased which is due to enhanced corrosion resistant, low maintenance and long life of the structure. Corten steel plates are used in sulphur rich environment and high temperature applications. Corten steel plates are used in heavy duty transport application.

Railway wagons and shipping containers are applications which are subjected to extreme climatic changes. Corten steel produces a hard protective rust layer (patina) when subjected to alternate climatic (wet/dry) changes. The life span of unpainted corten steel is 120 years which depends on many factors like area, climate and others. Weathering steels is commonly used in applications where water is not always in contact with corten steel. The major end use industries of corten steel are building & construction, transportation, art and architecture, decorative pieces, street lights, industrial etc. US, Mexico, Canada has a high demand for corten steel. Companies like United States Steel Corporation (US), Nippon Steel & Sumitomo Metal Corporation (Japan), HBIS Group (China), Tata Steel (India) are some of the leading companies in the weathering steel global market.

Corten steel has been segmented as Corten A and Corten B. The various forms of corten steel available in the market are plates, sheets, bars, tubes, stripes, rivets, coils etc. Corten steel is available as painted and unpainted form.

Weathering steel is a high strength low alloy steel, which contains a low percentage of carbon [6]. It is mostly used in automobile, building construction, bridges, telecommunication tower, and rail wagons [3]. Low carbon steel consists of Mn, P, Si, C, Cr, S, and Fe. The table1 below shows the chemical composition of low carbon steel (Corten steel A588 Grade Steel).

Table 1: Chemical Composition of Corten ASTM A588 Grade Steel Sheet

Element	C	Si	Mn	P	S	Cr	Fe
Composition (Wt %)	0.10-0.19	0.15-0.3	0.90-0.25	0.040	0.05	0.40-0.65	97-98.2

Laser beam welding (LBW) is defined as the joining of two metal plates permanently, without using filler material. In LBW laser is used as a heat source for welding. Laser welding is mostly used in automobile industry to prepare permanent joints. In the laser beam welding process, high-intensity laser beam melts the material and partially evaporates. Due to this intense heating and rapid cooling of the material, high thermal stress is developed on the welding zone. This leads to cracking on the weld zone and the heat affected zone. To remove thermal stress induced and to improve the strength of the material after welding, a process known as Post Weld Heat Treatment (PWHT) is performed [4]. PWHT can be used to reduce residual thermal stresses, as a method of hardness control, or even to enhance material strength [1].

LITERATURE SURVEY

T. Mohandas et.al (1997) in their research work concluded that post weld heat treatment (PWHT) will eliminate the soft zone. By using external cooling methods like copper backing and argon purging, the softening tendency can be reduced. Abdulkareem s. Aloraier et.al (2014) found that PWHT technique on multi layered welded low carbon steel had a lower hardness valued and low residual stress. The microstructure of the PWHT low carbon steel weld had ferrite and lower bainite and the microstructure of the HAZ had upper and lower bainite.

A. G. Olabi and M. S. J. Hashmi (1996) in their investigation found that soaking temperature of 650^{o}c for PWHT post welded heat treatment process has better results. The microstructure reviled ferrite and bainite in the HAZ and ferrite. The base material has ferrite and pearlite structures. But after PWHT process at 650^{o}C the tempered bainite with little percentage of precipitated carbide in HAZ. The hardness values have decreased with longer time duration. The toughness of the weld component is improved by longer cooling rates.

J. O. Olawale (2012) in his research work concluded that after PWHT process the hardness, tensile strength decreased where as the impact strength increased. This is due to the reduction in the residual stress developed during welding process. Abdulkareem S. Aloraier (2013) investigated the mechanical properties of PWHT treated low carbon steel multi layer welding specimens. Higher impact toughness was observed when temperature was higher than room temperature and just below 60^{o}C.

P. C. Chung et.al (2012) in his research attempted PWHT process to improve the toughness of the fine grained ERW welded steel pipes by normalizing and quenching process. Martensite and Bainite hard micro structures were formed with higher dislocation density. The toughness of the PWHT processed pipe had significant improvement. S. H. Baghjari, S. A. A. Akbari Mousavi (2013) has attempted two types of post-weld heat treatments (PWHTs) in order to increase the toughness and to reduce the hardness of the weld and the HAZ. One set of specimens where tempered for 2 hours and other set of specimens where austenitizied for 30 minutes at 1010 0C and then tempered for 2 hours.

Pingsha Dong (2014) et.al in their research work of PWHT of ferritic welding summarized that the residual stress relief mechanism in the PWHT process is creep induced stress relaxation. The current required to hold in PWHT process can be reduced to relief residual stress. The creep initiation temperature of the material can be found by parametric creep analysis. A. G. Olabi and M. S. J. Hashmi (1996) in research found that 650^{o}C soaking temperature is the most effective temperature. Slower cooling rates and longer time duration in PWHT process had considerably reduced the residual stress in the welded low carbon steel plate.

B. S. Yilbas et.al (2009) in his research on laser welding of low carbon steel found that there was temperature decay rate in the molten zone is lower than in the solid. This was because of the absorption and dissipation of the laser energy in the molten zone which is generated in the surface region and the residual stress predicted from the FEM agrees well with the XRD results, which is in the order of 100 MPa.

MATERIALS AND METHODS

Initially, the low carbon Corten A588 Grade Steel plate is cut into 300 x 150 x 2 mm dimension using WEDM (Wire Electrical Discharge Machining, Electronica EcoCut) by shear cutting process [6]. Then the plates are polished using 120 Emery wheel and Silicon Carbide powder. After polishing, the sample is cleaned using acetone solution. The chemical composition of the material is re-checked for assuring its quality by a Bench Top Optical Emission Spectrometer (Foundry Master Pro). The plates are welded by laser welding technique. Table (2) below shows the process parameters for laser beam welding of low carbon steel (Corten A588 Grade Steel).

Table 2: Parameter for Laser Beam Welding

Type of Welding	LBW
Shielding gas	Nitrogen
Time taken (sec)	100
Weld length(mm)	500
Weld speed(mm/sec)	30000
Pulse	51
Power (%)	70
Gas pressure	14000

Post Weld Heat Treatment (PWHT) Process

After the Laser beam welding of low carbon Corten A588 Grade Steel plates is completed, the welded plates is cut into 1 x 1 x 0.2 cm by shear cutting machine for Post weld Heat treatment process [2]. Then the PWHT samples that are cut, are placed inside muffle furnaces. It is maintained at 850^{o}c for 2 hours. After heating, the PWHT Laser welded samples are taken out for cooling by using air quenching, water quenching and furnace quenching. Surface hardness on the weld zone, heat affected zone and the Base material before and after PWHT is investigated using Vickers hardness testing machine (model no: VM–50) of load (20 kgf). Then, the samples were moulded and polished for microstructure analysis using Zeiss Axio Scope optical microscope. The samples were ground and polished on water lubricated silicon carbide abrasive papers of 180, 240, 320, 400 and 600 grit sizes. The samples were etched with 2 % Nital solution using the swabbing method with cotton wool soaked in the etchant.

EXPERIMENTAL WORK

Vickers's Hardness

The Vickers hardness test is carried out to determine the hardness of the welded plates. Figure 1 shows the hardness indentation on Laser welded Corten A588 Grade plate, after post weld heat treatment process.

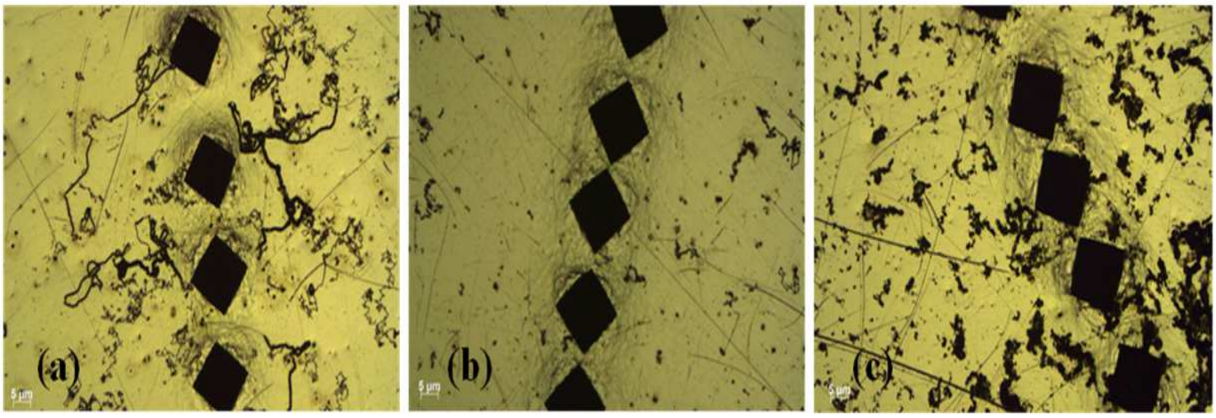
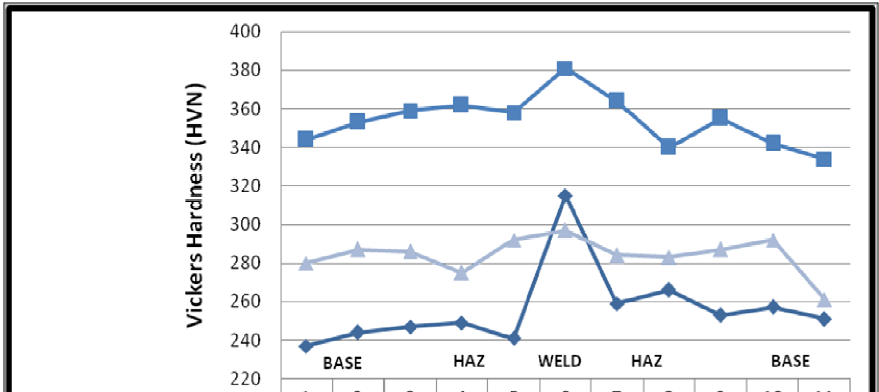


Figure 1: Vickers Hardness Indentation of LBW Welded Corten A588 Grade Steel Plate (a)Water Quenched (b) Air Quenched (c) Furnace Cooled.

Table 3: Vickers Hardness Values of Various Zones of LBW Welded Corten A588 Grade Steel Plate (a) Water Quenched (b) Air Quenched (c) Furnace Cooled



Positions	1	2	3	4	5	6	7	8	9	10	11
FURNACE QUENCHED	237	244	247	249	241	315	259	266	253	257	251
WATER QUENCHED	344	353	359	362	358	381	364	340	355	342	334
AIR QUENCHED	280	287	286	275	292	297	284	283	287	292	261

The table 3 shows the Vickers hardness number obtained at Base Metal, HAZ and on the weld Zone of the Laser welded Corten A588 Grade plate furnace quenched, water quenched and air quenched samples after the post weld heat treatment process. The time taken to apply load on quenched (water, air, and furnace) laser welded samples is 20sec, and a load of 20 kgf is applied on it.

In laser welded PWHT furnace quenched sample, the hardness at weld zone is (315 HVN). The average hardness at heat affected zone is (250 HVN) and the average hardness at base material is (250 HVN). But in laser welded PWHT water quenched sample, the hardness is higher at weld zone (381 HVN). The average hardness at heat affected zone is (361 HVN) and average hardness number at base is (349 HVN) due to higher cooling rate and less time consumption during quenching.

The laser welded PWHT air quenched sample has a lower hardness at weld zone (297 HVN) when compared to water quenched sample. The average hardness at heat affected zone is (288 HVN) and the average hardness at heat affected zone is (250 HVN) and the average hardness at base is (282 HVN). This is due to the medium cooling rate and less time consumption taken for the temperature to drop. From above graph, the highest Vickers hardness is at the Weld Zone, whereas the lowest HVN occurs at Heat Affected Zone [5].

Among the three modes of Quenching (furnace quenched, air quenched, and water quenched), the laser welded water quenched sample has highest hardness number (381 HVN) at the weld zone than furnace quenched sample (315 HVN) and air quenched sample (297 HVN). The hardness of the laser welded Water quenched sample is increased by 23% than that of air quenched sample and 16% than that of furnace quenched samples.

Micro Structure

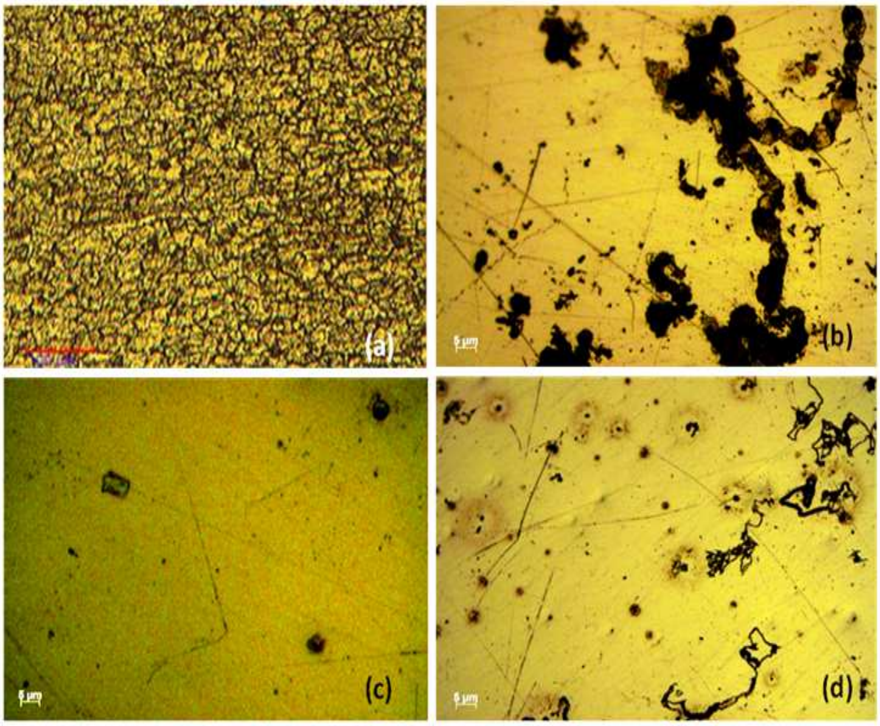


Figure 2: Microstructure of LBW Welded Corten A588 Grade Steel Plate (a) Base before PWHT (b) Furnace Quenched (c) Air Quenched (d) Water Quenched.

The microstructure properties of the Corten A588 Grade steel before and after PWHT Process can be revealed from figure 2 as shown below. The figure 2 (a) shows the microscopic views at 100x magnification of Corten A588 grade steel polished and itched in Nital Solution. It shows the base metal low carbon steel, which is elongated along the direction of rolling. The grain size of the ferrite present on the base metal is 25 to 30 microns.

The PWHT Furnace cooled samples forms inclusions of Iron carbide precipitation, which are wider chain like pit sites [8]. The grains are more of pearlite, less ferrite and more oxides which increases the rate of corrosion. This is due to the very slow rate of cooling when samples are cooled in the furnace itself. The PWHT Air cooled samples forms small pits on the surface. These samples has 90% of Ferrite and remaining pearlite due to faster cooling rate that that of the furnace cooling. The PWHT water cooled samples are cooled by dipping it into water after heating it to 850oc and

maintained for 2 hours. Here, the rate of cooling is very quick. The structure forms both pearlite and ferrite structure with small inclusions of carbide precipitate, which is spread all through the surface.

CONCLUSIONS

Among the three modes of cooling the PWHT Laser welded samples (furnace quenched, air quenched, and water quenched), the laser welded water quenched sample has the highest hardness of 381 HVN, at the weld zone than furnace quenched sample has a hardness of 315 HVN. The hardness of the laser welded Water quenched sample is increased by 23% than that of air quenched sample and 16% than that of furnace cooled samples.

Corten A588 Grade steel has ferrite and colonies of pearlite with a grain size of 25 to 30 microns. This microstructure change is due to the temperature and the chemical gradients that generate during the welding process and post weld heat treatment process. The PWHT water quenched samples has both pearlite and ferrite structure with small inclusions of carbide precipitate in forms of round small pits, which is spread all through the surface. PWHT process rate of cooling also place a major role on deciding the strength of the weld joint.

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